REMARKS

Prior to this Reply, Claims 1-18 and 21-101 were pending. Through this Reply, Claims 1-18 and 21-62 have been amended, Claim 63-101 have been cancelled without prejudice to, or disclaimer of, the subject matter recited therein, and Claims 102-141 have been added. Accordingly, Claims 1-18, 21-62 and 102-141 are now at issue in the present case.

I. Objection to Specification

The Examiner objected to the specification since reference number 224 refers to an integrator at page 12, lines 8-9 and at page 13, lines 12-15, but refers to a compensator and a compensator network at page 12, lines 21-22 and page 19, lines 18-19. The substitute specification provided herein overcomes these objections since reference number 224 has been deleted.

II. Drawing Objections

The Examiner objected to the drawings since reference number 224 designates both an integrator and a compensator. The replacement figures provided herein overcome this objection since reference number 224 has been deleted.

III. Claim Rejections Under 35 U.S.C. § 112

The Examiner rejected Claims 40, 41, 52-54, 85-87, 91-96 and 99-101 under 35 U.S.C. § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

Claim 40 is rejected since "said bipolar switch" lacks antecedent basis. Claim 40 has been amended to delete this terminology.

Claims 52, 53, 85, 86, 91 and 92 are rejected since "said compensator" lacks antecedent basis. Claims 52 and 53 have been amended to delete this terminology, and Claims 85, 86, 91 and 92 have been cancelled.

Claims 61-63 and 99 are rejected since "said compensating step" lacks antecedent basis. Claims 61 and 62 have been amended to delete this terminology, and Claims 63 and 99 have been cancelled.

IV. <u>Rejection of Claims 1, 6-18, 21-26, 28, 64 and 67-73 under 35 U.S.C. 102(e) – Rosenberg</u>

Claims 1, 6-18, 21-26, 28, 64 and 67-73 are rejected under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent No. 6,300,937 to Rosenberg (hereinafter "Rosenberg").

Rosenberg discloses computer system 10 that provides a user with force feedback (physical sensations) in a virtual reality environment. Computer system 10 includes host computer system 12 and interface device 14. Host computer system 12 implements a host application program with which user 22 interacts via interface device 14.

Host computer system 12 includes host processor 16, system clock 18, display device 20 (such as a CRT or goggles) and audio output device 21 (such as speakers). Host computer system 12 can include storage devices such as a disk drive, floppy drive or CD ROM drive coupled to host processor 16.

Interface device 14 includes local microprocessor 26, sensors 28, actuators 30, user object 34, sensor interface 36, actuator interface 38, other input 39, power supply 40 and safety switch 41.

User object 34 is a device or article that can be grasped or otherwise contacted or controlled by user 22, such as a joystick, mouse, trackball, stylus, steering wheel, medical instrument, pool cue, hand grip, knob or button.

Sensors 28 sense the position, motion and/or other characteristics of user object 34. Sensors 28 can be a digital optical encoder, strain gauge or velocity sensor.

Local microprocessor 26 provides control signals to actuators 30 (via actuator interface 38 and safety switch 41) in response to commands from host computer system 12 (via bus 24), manipulations by user 22 (via other input 39) and signals from sensors 28 (via sensor interface 36). For example, local microprocessor 26 provides low-level force commands to actuators 30 in response to receiving the commands from host computer system 12. As another example, local microprocessor 26 manages low-level force control loops (reflexes) to sensors 28 and actuators 30 in accordance with high-level commands from host computer system 12.

Actuators 30 transmit force to user object 34 in one or more directions along one or more degrees of freedom in response to control signals from microprocessor 26 (via actuator interface 38). Actuators 30 include a separate actuator for each degree of freedom along which force is transmitted. Actuators 30 include linear current control motors, DC servo motors and voice coils.

Actuator interface 38 includes digital to analog controller (DAC) circuit 44 and power amplifier circuit 46.

DAC circuit 44 includes DAC 48, op amp 50 and op amp 52. DAC 48 converts a digital signal representing a force value from local microprocessor 26 into an analog signal, op amp 52 provides the analog signal in the range of zero to –5 volts and op amp 54 shifts the analog signal into a symmetrical bipolar range of –2.5 to +2.5 volts.

Power amplifier circuit 46 includes a transconductance stage composed of amplifier 54 and several resistors and a second amplifier stage composed of amplifier 56, several resistors and capacitor C. The transconductance stage converts the analog low-power control voltage from op amp 54 into a proportional current signal, and the second amplifier stage provides additional current capacity by enhancing the voltage swing across actuators 30.

Claim 1 recites "In a disk drive that includes a head, a disk, a microprocessor, a driver and a voice coil motor, wherein the head reads from and writes to the disk, the microprocessor provides a command current to the driver, the driver provides a coil current to the voice coil motor in response to the command current, the voice coil motor radially positions the head relative to the disk in response to the coil current, and the coil current flows through a coil in the voice coil motor." Claims 14 and 23 recite similar limitations, Claims 6-13 depend from Claim 1, Claims 15-18, 21 and 22 depend from Claim 14, Claims 24-26 and 28 depend from Claim 23 and Claims 64 and 67-73 have been cancelled.

Rosenberg fails to teach or suggest that interface device 14, local microprocessor 26, sensors 28, actuators 30 or actuator interface 38 is in a disk drive. Instead, host computer system 12 is connected to interface device 14 by bus 24, and host computer system 12 may include a disk drive. Rosenberg also fails to teach or suggest that actuators 30 radially position a head relative to a disk. Instead, actuators 30 move user object 34.

Claim 1 also recites "the driver comprising . . . a sensor that provides a sense current by sensing the coil current." Claims 14 and 23 recite similar limitations. Rosenberg fails to teach or suggest that sensors 28 sense a coil current in actuators 30. Instead, sensors 28 sense the position, motion and/or other characteristics of user object 34.

Claim 1 also recites "the driver comprising . . . a comparator that provides an error current by determining a difference between the command current and the sense current." Claims 14 and 23 recite similar limitations. Rosenberg fails to teach or suggest that local microprocessor 26 or actuator interface 38 determines the control signal for actuators 30 as a difference between the command from host computer system 12 and the signal from sensors 28. Instead, local microprocessor 26 determines the control signal in response to the command and the sensor signal, and actuator interface 38 provides digital-to-analog conversion, voltage-to-current conversion and amplification on the control signal.

Claim 1 also recites "the driver comprising . . . an integrator that provides an integrated error current by integrating the error current; and an amplifier that provides the coil current by amplifying the integrated error current." Claims 14 and 23 recite similar limitations.

Rosenberg fails to teach or suggest that the control signal between local microprocessor 26 and actuators 30 is integrated. Instead, actuator interface 38 provides digital-to-analog conversion, voltage-to-current conversion and amplification on the control signal.

The Examiner asserts that Rosenberg discloses "a driver having a current control device for a voice coil motor, used in a disk drive comprising a sensor (Fig. 2: R2) to sense a coil current in a voice coil motor (e.g. Col. 4:13-15); a transconductance amplifier (e.g. Fig. 2:54) to detect an error current by comparing a coil current (current across R2) and a command current (e.g. Fig. 2:Vin) and means (Fig 2:R,C,56) to integrated the error current into a coil current."

Rosenberg fails to teach or suggest that resistor R2 senses the current that passes through actuators 30, and the Examiner has no support or reasoning for this statement. Rosenberg also fails to teach or suggest that amplifier 54 generates an output current by determining a difference between the current received from local microprocessor 26 and the current that flows through

actuators 30, and the Examiner has no support or reasoning for this statement. Rosenberg also fails to teach or suggest that capacitor C transforms the second stage amplifier into an integrator, and the Examiner has no support or reasoning for this statement.

Rosenberg indicates that capacitor C enhances the voltage swing across actuators 30:

> The second amplifier stage, including amplifier 56, resistors, and a capacitor C, provides additional current capacity by enhancing the voltage swing of the second terminal 57 of motor 30. (Col. 12, lines 50-54.)

Thus, the Examiner has mischaracterized amplifier 54, resistor R2 and capacitor C by depicting functions and operations they do not perform.

V. Rejection of Claims 44-46, 48 and 49 under 35 U.S.C. 102(e) – Schlager

Claims 44-46, 48 and 49 are rejected under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent No. 6,600,618 to Schlager (hereinafter "Schlager").

Schlager discloses driving circuit 10 for voice coil motor 75. Driving circuit 10 includes controller 12, feedback network 18 and power supply 95 composed of FETs 44, 46, 48 and 50 coupled as an H-bridge. Driving circuit 10 compensates for temperature-induced mechanical changes during ramp loading and unloading of heads 78 using velocity feedback from voice coil motor 75.

Claim 44 recites "the driver provides a coil current to the voice coil motor . . . the voice coil motor radially positions the head relative to the disk in response to the coil current . . . the driver comprising . . . an integrator that provides an integrated error current by integrating the error current . . . first and second amplifiers that provide the coil current by amplifying the integrated error current." Claim 48 recites similar limitations, Claims 45 and 46 depend from Claim 44 and Claim 49 depends from Claim 48.

Schlager fails to teach or suggest that driving circuit 10 includes an integrator between controller 12 and power supply 95. Instead, direct connections are between controller 12 and power supply 95.

The Examiner correctly recognizes that Schlager lacks the integrator by not rejecting Claims 1, 14 or 23 based on Schlager.

VI. Rejection of Claims 50-52, 57-59, 61, 63, 84, 85, 90 and 97 under 35 U.S.C. 102(e) – Ng

Claims 50-52, 57-59, 61, 63, 84, 85, 90 and 97 are rejected under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent No. 6,388,413 to Ng et al. (hereinafter "Ng").

Ng discloses disk drive 100 that includes transducing head 126, a voice coil motor composed of voice coil 128, first magnet 130 and second magnet 131, power amplifier 238 and subtractor 254. Subtractor 254 generates a control signal proportional to the difference between the actual velocity of transducing head 126 and a demand velocity, and power amplifier 238 receives the control signal and provides a current to voice coil 128.

Claim 50 recites "the driver provides a coil current to the voice coil motor . . . the voice coil motor radially positions the head relative to the disk in response to the coil current . . . the driver comprising . . . an integrator that provides an integrated error current by integrating the error current . . . an amplifier that provides the coil current by amplifying the integrated error current." Claim 58 recites similar limitations, Claims 51, 52 and 57 depend from Claim 50, Claims 59 and 61 depend from Claim 58 and Claims 63, 84, 85, 90 and 97 have been cancelled.

Ng fails to teach or suggest that disk drive 100 includes an integrator between power amplifier 238 and subtractor 254. Instead, a direct connection is between power amplifier 238 and subtractor 254.

The Examiner correctly recognizes that Ng lacks the integrator by not rejecting Claims 1, 14 or 23 based on Ng.

VII. Rejection of Claims 1, 12, 14, 23, 28 and 64 under 35 U.S.C. 102(b) – Jove

Claims 1, 12, 14, 23, 28 and 64 are rejected under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 5,270,882 to Jove et al. (hereinafter "Jove").

Jove discloses head disk assembly 10 that includes MR element Rmr, an amplifier circuit, disk D, drive spindle 12, actuator 14 and arm electronics module 16. The MR element reads from the disk D, the actuator 14 positions the MR element relative to the disk D and the amplifier circuit provides fixed read bias current to the MR element and senses signal current generated from the MR element.

Claim 1 recites "a disk drive that includes a head, a disk, a microprocessor, a driver and a voice coil motor, wherein the head reads from and writes to the disk . . . the driver provides a coil current to the voice coil motor . . . the voice coil motor radially positions the head relative to the disk in response to the coil current . . . the driver comprising . . . a sensor . . . a comparator . . . an integrator . . . and an amplifier." Claims 14 and 23 recite similar limitations, Claim 12 depends from Claim 1, Claim 28 depends from Claim 23 and Claim 64 has been cancelled.

Jove fails to teach or suggest a driver for actuator 14, much less a driver that includes the features mentioned above. Instead, the amplifier circuit drives the MR element and has nothing to do with actuator 14.

The Examiner asserts that Jove discloses "a driver having a current control device for a voice coil motor, used in a disk drive comprising a sensor (1:R1) to sense a coil current in a voice coil motor (Fig. 1:Rmr); a transconductance amplifier (Fig. 1:g0) to detect an error current

by comparing a coil current and a command current (col. 2:47-50) and means (fig 1:C1) to integrated the error current into a coil current (col.2:40-53)."

Jove indicates that Rmr is the magnetoresistive element:

> As illustrated in FIG. 1, the amplifier circuit comprises a magnetoresistive (MR) element Rmr which senses binary data from a magnetic recording disk D, a resistor R1 for setting gain of the circuit, a single supply voltage source +V and a reference voltage source Vref referenced to said supply voltage +V. (Col. 2, lines 19-24.)

Thus, the Examiner has mischaracterized the magnetoresistive element as actuator 14.

VIII. <u>Rejection of Claims 30, 34-45, 74 and 77-80 under 35 U.S.C. 102(b) – Salina</u>

Claims 30, 34-45, 74 and 77-80 are rejected under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 6,023,143 to Salina et al. (hereinafter "Salina").

Salina discloses a driving system for a voice coil motor. The driving system includes a sense amplifier, an error amplifier, a switch S1, a pulse width modulation (PWM) converter and a linear amplifier. The driving system switches between the PWM converter and the linear amplifier to drive the voice coil motor.

Claim 30 recites "the driver provides a coil current to the voice coil motor . . . the voice coil motor radially positions the head relative to the disk in response to the coil current . . . the driver comprising . . . an integrator that provides an integrated error current by integrating the error current . . . first and second amplifiers that provide the coil current by amplifying the integrated error current." Claims 38 and 44 recite similar limitations, Claims 34-37 depend from Claim 30, Claims 39-43 depend from Claim 38, Claim 45 depends from Claim 44 and Claims 74 and 77-80 have been cancelled.

Salina fails to teach or suggest that the driver includes an integrator between the error amplifier and the voice coil motor. Instead, the switch S1, the PWM converter and the linear amplifier are between the error amplifier and the voice coil motor.

The Examiner correctly recognizes that Salina lacks the integrator by not rejecting Claims 1, 14 or 23 based on Salina.

IX. Rejection of Claims 30-34, 36-48, 50-63, 74-77 and 79-101 under 35 U.S.C. 102(b) – Taylor

Claims 30-34, 36-48, 50-63, 74-77 and 79-101 are rejected under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 3,936,876 to Taylor (hereinafter "Taylor").

Taylor discloses driver circuit 26 for voice coil winding 20. Driver circuit 26 includes drivers 53 and 54 and current sense circuit 55. Compensator 25 provides an error signal to drivers 53 and 54.

Claim 30 recites "the driver provides a coil current to the voice coil motor . . . the voice coil motor radially positions the head relative to the disk in response to the coil current . . . the driver comprising . . . an integrator that provides an integrated error current by integrating the error current . . . first and second amplifiers that provide the coil current by amplifying the integrated error current." Claims 38, 44, 48, 50 and 58 recite similar limitations, Claims 31-34, 36 and 37 depend from Claim 30, Claims 39-43 depend from Claim 38, Claims 45-47 depend from Claim 44, Claims 51-57 depend from Claim 50, Claims 59-62 depend from Claim 58 and Claims 63, 74-77 and 79-101 have been cancelled.

Taylor fails to teach or suggest that driver circuit 26 includes an integrator between compensator 25 and drivers 53 and 54. Instead, resistor 141 is between compensator 25 and drivers 53 and 54.

The Examiner correctly recognizes that Taylor lacks the integrator by not rejecting Claims 1, 14 or 23 based on Taylor.

X. Rejection of Claims 38, 42, 43, 50, 55-58, 61 and 63 under 35 U.S.C. 102(b) – Hassan '717

Claims 38, 42, 43, 50, 55-58, 61 and 63 are rejected under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 5,821,717 to Hassan et al. (hereinafter "Hassan '717").

Hassan '717 discloses disk drive 1 that includes error amplifier 112, predrive amplifier 113, sense amplifier 114, actuator power block 220 (mislabeled 210 in Fig. 2) and actuator motor 300. Sense amplifier 114 provides a sense signal proportional to the current through actuator motor 300, error amplifier 112 provides an error signal based on a current command signal and the sense signal, predrive amplifier 113 provides a bi-directional preamplified signal that controls both the direction and magnitude of actuator motor 300 based on the error signal, and actuator power block 220 drives actuator motor 300 based on the preamplified signal.

Claim 50 recites "the driver provides a coil current to the voice coil motor . . . the voice coil motor radially positions the head relative to the disk in response to the coil current . . . the driver comprising . . . an integrator that provides an integrated error current by integrating the error current . . . an amplifier that provides the coil current by amplifying the integrated error current." Claims 38 and 58 recites similar limitations, Claims 42 and 43 depend from Claim 38, Claims 55-57 depend from Claim 50, Claim 61 depends from Claim 58 and Claim 63 has been cancelled.

Hassan '717 fails to teach or suggest that disk drive 1 includes an integrator between error amplifier 112 and actuator motor 300. Instead, predrive amplifier 113 and sense amplifier 114 are between error amplifier 112 and actuator motor 300.

The Examiner correctly recognizes that Hassan '717 lacks the integrator by not rejecting Claims 1, 14 or 23 based on Hassan '717.

XI. Rejection of Claim 2 under 35 U.S.C. 103(a) – Rosenberg and Ratliff

Claim 2 is rejected under 35 U.S.C. § 103(a) as being unpatentable over Rosenberg in view of U.S. Patent No. 6,088,185 to Ratliff et al. (hereinafter "Ratliff").

Claim 2 depends from Claim 1. Rosenberg fails to teach or suggest all of the elements of Claim 1, as mentioned above, and Ratliff fails to cure this deficiency.

XII. Rejection of Claims 2, 4, 5 and 65 under 35 U.S.C. 103(a) – Rosenberg and Harwood

Claims 2, 4, 5 and 65 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Rosenberg in view of U.S. Patent No. 5,491,394 to Harwood et al. (hereinafter "Harwood").

Claims 2, 4 and 5 depend from Claim 1, and Claim 65 has been cancelled. Rosenberg fails to teach or suggest all of the elements of Claim 1, as mentioned above, and Harwood fails to cure this deficiency.

XIII. Rejection of Claims 3, 27, 29 and 66 under 35 U.S.C. 103(a) – Rosenberg and Hassan '717

Claims 3, 27, 29 and 66 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Rosenberg in view of Hassan '717.

Claim 3 depends from Claim 1, Claim 27 depends from Claim 23, and Claim 66 has been cancelled. Rosenberg fails to teach or suggest all of the elements of Claims 1 and 23, as

mentioned above, and Hassan '717 fails to cure this deficiency. Likewise, Rosenberg fails to teach or suggest all of the elements of Claim 29, and Hassan '717 fails to cure this deficiency.

XIV. New Claims

Claims 102-141 have been added. No new matter has been added.

Claim 102 is allowable for at least the same reasons as Claim 1. Furthermore, Claim 102 recites "the coil includes first and second coils and a center tap, and the first and second coils are coupled to one another at the center tap . . . the driver comprises . . . an amplifier that provides the coil current through the first and second coils in series while the center tap floats by amplifying the integrated error current in response to a track following operation; and a transistor that provides the coil current through the center tap such that the coil current is divided between and flows in parallel through the first and second coils in response to a seek operation." Rosenberg, Schlager, Ng, Jove, Salina, Hassan '717, Ratliff and Harwood fail to teach or suggest a coil that includes and first and second coils coupled at a center tap, and in Taylor the center tap of voice coil winding 20 is tied to a 24 volt supply. Claims 103-111 depend from Claim 102 and are allowable for at least the same reasons as Claim 102.

Claim 112 is allowable for at least the same reasons as Claim 102. Claims 113-121 depend from Claim 112 and are allowable for at least the same reasons as Claim 112.

Claim 122 is allowable for at least the same reasons as Claim 102. Claims 123-127 depend from Claim 122 and are allowable for at least the same reasons as Claim 122.

Claim 127 is allowable for at least the same reasons as Claim 102. Claims 128-131 depend from Claim 127 and are allowable for at least the same reasons as Claim 127.

Claim 132 is allowable for at least the same reasons as Claim 102. Claims 133-137 depend from Claim 132 and are allowable for at least the same reasons as Claim 132.

Claim 137 is allowable for at least the same reasons as Claim 102. Claims 138-141 depend from Claim 137 and are allowable for at least the same reasons as Claim 137.

XV. Other Amendments to Claims

The claims have been amended to improve clarity. No new matter has been added.

XVI. Amendments to Specification

A substitute specification without claims (and a marked-up version thereof) is provided herein under 37 C.F.R. 1.125 to improve clarity of the specification. No new matter has been added.

Applicant respectfully requests that the substitute specification be entered.

XVII. Amendments to Drawings

Applicant is submitting replacement Figures 1-4 (contained on Replacement Sheets 1-4) to improve the quality of the drawings.

Figure 1 has been modified to clarify head 12, disk 14, spindle motor 16, preamplifier 18, channel 20, microprocessor 22, digital-to-analog converter 24, driver 26, actuator assembly 28, voice coil motor 30, actuator arm 32, coil 34 and permanent magnet 36 and to delete reference numerals 29, 35 and 38.

Figure 2 has been modified to clarify driver 26, voice coil motor 30, coil 34, power chip 40, sense resistors 42 and 44, capacitor 46, phase resistor 48, transconductance amplifier 50,

comparator 52, error buffer 54, amplifiers 56 and 58, transistors 60 and 62, reference voltage generator 64, voltage shifter 66, switch 68, coils 70 and 72, center tap 74, interface 76, terminals 80, 82 and 84, the command current and voltages Vcc and Vcc/2 and to delete labels NPOR, VCOMP, VCMA, SENAL, VCMCT, VSENBL, VCMB, GNDV, MOTOR A, MOTOR B, MOTOR CT and the arrow within coil 34.

Figure 3 has been modified to clarify driver 26, voice coil motor 30, coil 34, power chip 40, sense resistors 42 and 44, transconductance amplifier 50, transistors 60 and 62, reference voltage generator 64, switch 68, coils 70 and 72, center tap 74, terminals 80, 82 and 84, programmable comparator 86, polarity comparator 88, predriver logic circuits 90 and 92, transistors 94, 96, 98 and 100, the command current, voltage Vcc and Toff programming and to delete labels NPOR, VCMA, SENAL, VCMCT, VSENBL, VCMB, GNDV, MOTOR A, MOTOR B and MOTOR CT.

Figure 4 has been modified to clarify driver 26, voice coil motor 30, coil 34, power chip 40, sense resistors 42 and 44, capacitor 46, phase resistor 48, transconductance amplifier 50, comparator 52, error buffer 54, transistors 60 and 62, reference voltage generator 64, switch 68, coils 70 and 72, center tap 74, terminals 80, 82 and 84, transistors 94, 96, 98 and 100, retract sequencer 102, reference retract velocity generator 104, amplifier 106, predriver logic circuit 108, the command current, voltage VBEMF, the brake VCM, retract head and brake spindle motor control signals and to delete labels NPOR, VCMA, SENAL, VCMCT, VSENBL, VCMB, GNDV, MOTOR A, MOTOR B and MOTOR CT.

No new matter has been added. Figures 1-4 constitute all of the drawings of the application.

XVIII. Additional Claim Fees

In determining whether additional claim fees are due, reference is made to the Fee Calculation Table (below).

Fee Calculation Table

	Claims Remaining After Amendment		Highest Number Previously Paid For	Present Extra	Rate	Additional Fee
Total (37 CFR 1.16(c))	100	Minus	100	= 0	x $50 =	$ 0.00
Independent (37 CFR 1.16(b))	16	Minus	16	= 0	x $200 =	$ 0.00

As set forth in the Fee Calculation Table (above), Applicant previously paid claim fees for one hundred (100) total claims and for sixteen (16) independent claims. Accordingly, Applicant believes that no additional fees are due. Nevertheless, Applicant hereby authorizes the Commissioner to charge Deposit Account No. 50-2198 for any fee deficiencies associated with filing this paper.

XIX. Conclusion

It is believed that the above comments establish patentability. Applicant does not necessarily accede to the assertions and statements in the Office Action, whether or not expressly addressed.

Applicant believes that the application appears to be in form for allowance. Accordingly, reconsideration and allowance thereof is respectfully requested.

The Examiner is invited to contact the undersigned at the below-listed telephone number regarding any matters relating to the present application.

Respectfully submitted,

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MARKED-UP VERSION OF

SUBSTITUTE SPECIFICATION UNDER 37 C.F.R. 1.125

DRIVER ~~DEVICE~~ AND METHOD FOR CONTROL OF ~~PURE TORQUE~~ VOICE COIL MOTOR IN DISK DRIVE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to disk drives~~the field of magnetic data read/write devices~~, and more particularly, to a driver ~~device~~ and method for ~~to~~ controlling a voice coil motor in a disk drive ~~with a circuit~~.

Discussion of the Related Art

Disk drive 10 includes head 12, disk 14, spindle motor 16, preamplifier 18, channel 20, microprocessor 22, digital-to-analog converter (DAC) 24, driver 26 and actuator assembly 28 that includes voice coil motor (VCM) 30 and actuator arm 32. Furthermore, VCM 30 includes coil 34 and permanent magnet 36.

Head 12 is a transducer that reads data from and writes data to disk 14. Head 12 is attached to or formed integrally with a slider. Disk 14 is a magnetic ~~In disk drives, a~~ storage medium that stores data in concentric tracks~~, such as a magnetic disk, is rotated~~. S~~A spindle motor may cause the disk to rotate within the disk drive. The disk may be mounted to a spindle attached to the spindle motor. The~~ spindle motor 16 rotates ~~the spindle and the~~ disk 14 so that ~~to provide read/write access to the disk.~~ head 12 is supported by a cushion of air (air bearing) at a flying height in close proximity to disk 14.

Preamplifier 18 amplifies analog read signals from head 12 and passes the read signals to channel 20, and channel 20 demodulates the read signals and sends digital signals to microprocessor 22. Microprocessor 22 sends a digital command signal to DAC 24, which transforms the digital command signal into an analog command signal, and driver 26 receives the analog command signal and sends a coil current to VCM 30.

VCM 30 is coupled to actuator arm 32, which is a suspension that supports head 12. VCM 30 rotates actuator arm 32 about a pivot point to ~~Disk drives may utilize a magnetic disk having concentric data tracks defined for storing data, a magnetic recording head, or transducer, for reading data from and/or writing data to the various data tracks, a slider for supporting the transducer in proximity to the data tracks in a flying mode above the storage media, a suspension assembly for supporting the slider and the transducer over the data tracks, and a positioning actuator coupled to the transducer/slider/suspension mechanism for~~ move~~ing~~ head 12 radially across disk 14 ~~the transducer across the media~~ to selected ~~the desired data~~ tracks during seek operations, and maintains head 12 above selected tracks ~~center line~~ during track following ~~a read or write~~ operations.

VCM 30 is a fast response, direct current, pure torque motor that ~~The transducer is attached to or is formed intregally with the slider that supports the transducer above the data surface of the storage disk by a cushion of air, referred to as the air bearing, generated by the rotating disk.~~

~~The actuator positions the transducer over the correct track according to the data desired on a read operation or to the correct track for placement of the data during a write operation. The actuator is controlled to position the transducer over the desired data track by shifting the mechanism assembly across the surface of the disk in a direction generally transverse to the data tracks. The actuator may include a single positioner arm extending from a pivot point, or, alternatively, a plurality of positioner arms arranged in a comb-like fashion extending from a pivot point. A rotary voice coil motor ("VCM") is attached to the rear portion of the actuator assembly to power movement of the actuator over the disk.~~

~~The VCM is located at the rear portion of the actuator assembly and~~ includes ~~comprises a~~ top and bottom plates (not shown) and ~~spaced above a bottom plate with a magnet or pair of magnets therebetween.~~ coil 34 and permanent magnet 36 therebetween. The ~~The~~ coil current passes through coil 34 to generate a magnetic field that interacts with the magnetic field of permanent magnet 36 to create torque that rotates actuator arm 32~~VCM~~ and positions head 12~~also may include an electrically conductive coil disposed within the rearward extension of the actuator assembly and between the top and bottom plates, while overlying the magnet in a plane parallel to the magnet. In operation, current passes through the coil and interacts with the~~

~~magnetic field of the magnet so as to rotate the actuator assembly around its pivot to position the transducer as desired~~. Coil 34 is a stacked coil with two coils stacked relative to one another. When the coil current passes through the coils in the same direction the coils generate forces in opposite rotational directions that cancel each other and no torque is generated, and when the coil current passes through the coils in opposite directions the coils generate forces in the same rotational direction that supplement one another and torque is generated. In addition, mechanical ~~The VCM may be a fast response, direct current ("DC") motor.~~

disturbance forces are balanced so that the coil current puts electrical energy into coil 34 that creates desired motion without wasting moment (pure torque).

Disk drive 10 receives read and write commands from a host computer (not shown), and in response, performs read and write operations in which head 12 accesses different tracks on disk 14. The read and write operations include servo operations which include seek and track following operations. During a servo operation, microprocessor 22 receives servo position information from head 12, implements a servo control program by executing an estimator control loop program, and commands driver 26 to send a coil current to VCM 30 ~~During operation of the disk drive, the actuator is driven by the VCM and positioned radially over the disk surface under the control of a positioning servo system. The VCM may be controlled by a microcontroller integrated into the disk drive components. The servo system is designed to~~ to accurately position ~~the~~ head 12 ~~read/write transducer~~ over thea selected ~~data~~ track ~~on the disk~~ in as short a time as possible to enable the data transfer between head 12 and disk 14. ~~This action may be known as a seek operation. The servo system also may maintain the read/write transducer position over the data track as accurately as possible. This action may be known as a track following operation.~~

~~Performance of the~~ Ddisk drive 10 increases its storage capacity by reducing the flying height of head 12 and by reducing the ~~may be increased or made more efficient by making the~~ track spacing on disk 14~~e between tracks~~. Reduced flying height increases the bits-per inch (BPI) on disk 14, and reduced track spacing increases the tracks-per-inch (TPI) on disk 14. However, actuator assembly 28 is a non-rigid structure that exhibits ~~smaller and by applying rapid forces in a short time. The access speed between tracks may also be increased. Motor resolution should be very fine to track data on the disk with a very tight tolerance. If able to~~

~~follow the data track accurately, then one might be able to write tracks closer to increase disk drive capacity.~~

~~Actuator assemblies may have~~ mild vibration at resonant frequencies during the seek and track following operations. As a result, actuator assembly 28 creates mechanical disturbance that can degrade the performance of disk drive 10 as the flying height and the track spacing are reduced. For instance, at low flying height the mechanical disturbance can cause head 12 to contact disk 14, thereby damaging head 12 as it sticks to varnish on disk 14 and ruining data at the contact point on disk 14. Likewise, at high TPI the mechanical disturbance can limit the ~~that adversely affect the performance of the servo system.~~ servo bandwidth due to poor frequency response at t~~T~~he lowest resonant frequencie~~resonances having the lowest frequencies limit the bandwidth of the servo system, which results in poor high frequency response and degraded disk drive performance. Because the mechanical assembly is not rigid, mechanical frequencies exist. When the head is in motion or sitting over a track, a moderate vibration may still affect positioning of the head. The VCM should account for these disturbances~~s.

Actuator assemblies have been designed with secondary motors that position the head relative to the disk and reduce the mechanical disturbance. However, dual-stage actuators require more ~~Attempts have been made to reduce the amount of disturbance in the actuator assembly. One attempt includes an additional motor that acts as a secondary actuator. Two motors may be used to correct the position of the head over the track. Disturbance may be reduced by letting the second actuator correct some of the vibration. Two motors, however, increase~~ space ~~requirements~~ in ~~for~~ the disk drive.

~~In addition, capacity of storage media is being pushed by different media and different recording techniques. One issue is attempting to retrieve a larger signal off of the disk by "flying lower," or closer to the surface of the disk. When flying lower, the disk drive should be mindful of bumps, varnish and the like that may contact the head. When the head lands on the surface of the disk, it tends to stick which may damage the head. Further, every time the head touches the disk, the risk exists that the data under the head may be ruined.~~

Th~~us,~~ere is therefore ~~attempts to increase capacity and speed in disk drives have resulted in~~ a need for improved position ~~finer~~ control of a head ~~over the mechanical assemblies of~~ in a disk drives.

SUMMARY OF THE INVENTION

The present invention provides a driver for a ~~To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described, a driver device and method for a pure torque~~ voice coil motor in a disk drive~~is disclosed~~.

T~~According to an embodiment of the present invention,~~ he ~~a~~ driver ~~having a current control device for a voice coil motor in a disk drive is provided. The driver~~ includes a sensor that provides a sense current by sensing ~~to sense~~ a coil current in the voice coil motor, a comparator that provides an error current by determining a difference between a command current and the sense current, an integrator that provides an integrated error current by integrating the error current, and an amplifier that provides the coil current by amplifying the integrated error current~~. The driver also includes a transconductance amplifier to detect an error current from the coil current and the command current. The driver also includes a compensator to integrate the error current into the coil current~~.

~~According to another embodiment of the present invention, a method for tracking a disk using a voice coil motor coupled to a driver is disclosed. The method includes sensing a coil current in the voice coil motor. The method also includes determining an error current from the coil current and a command current. The method also includes integrating the error current into the coil current.~~

In ~~According to another~~ embodiment~~of the present invention~~, the sensor includes a sense resistor that provides a sense voltage in response to the coil current and a transconductance amplifier that provides the sense current in response to the sense voltage~~a current control device for a voice coil motor driver is disclosed. The voice coil motor driver is coupled to a microprocessor to receive commands specifying a command current for a voice coil motor. The current control device includes an amplifier to drive the voice coil motor with a coil current. The current control device also includes a compensator circuit to integrate an error current with the command current to generate the coil current. The error current is detected with a sensor coupled between the amplifier and the voice coil motor.~~ T

~~According to an embodiment of the present invention,~~he integrator includes a capacitor coupled to a node between the comparator and the amplifier~~a driver having a current control device for a voice coil motor is disclosed. The driver includes an amplifier to drive the voice~~

~~coil motor with a coil current. The coil current flows from one terminal of the voice coil motor to another terminal. Both terminals are coupled to the driver. The driver also includes a sensor to sense the coil current in the voice coil motor. The sensor is coupled between the amplifier and the voice coil motor. The driver also includes a current sense amplifier to amplify a voltage across the sensor. The voltage correlates to the coil current. The driver also includes a transconductance amplifier coupled to the current sense amplifier to receive the voltage and a command current. The transconductance amplifier calculates an error current. The driver also includes an integrator coupled to the transconductance amplifier to integrate the error current into the command current to determine the coil current~~. T

~~According to another embodiment of the present invention,~~he coil includes first and second coils and a center tap therebetween. The amplifier includes first and second amplifiers, the first amplifier is coupled to the first coil, the second amplifier is coupled to the second coil, the first amplifier is coupled to the second coil and the center tap through the first coil, and the second amplifier is coupled to the first coil and the center tap through the second coil. The driver also includes first and second transistors coupled to the center tap and coupled to the first and second coils through the center tap~~a driver having a current controller for a voice coil motor is disclosed. The driver includes a set of transistors coupled to the coil motor by a center tap. The set of transistors supply a coil current having a waveform to the center tap. The driver also includes a current sense amplifier to detect the coil current. The driver also includes a comparator to shape a command current waveform to the coil current wave form. The driver also includes a bipolar switch control to receive the command current waveform and to saturate the set of transistors~~.

In ~~According to~~ another embodiments~~ of the present invention~~, the first amplifier is coupled to the first coil by a first terminal, the second amplifier is coupled to the second coil by a second terminal, the first and second transistors are coupled to the center tap by a third terminal, and an interface between the driver and the voice coil motor consists of the first, second and third terminals~~ a method for controlling a voice coil motor accessing a track on a magnetic disk with a driver is disclosed. The method includes supplying a coil current to the voice coil motor. The method also includes amplifying the coil current. The method also includes shaping a command current waveform according to the coil current~~.

In ~~According to~~ another embodiment~~ of the present invention~~, the first and second amplifiers provide the coil current through the first and second coils in series, the first and second transistors are turned off and the center tap floats and in response a track following operation~~current control device within a driver for controlling a voice coil motor to seek a track on a storage media is disclosed. The current control device includes a coil current supplied to the voice coil motor along a center tap coupled to the driver. The current control device also includes a comparator to shape a waveform of a specified command current in accordance with a waveform of the coil current. The command current drives a bipolar switch coupled to the center tap~~.

In ~~According to~~ another embodiment~~ of the present invention, a driver having a current control device for controlling a voice coil motor during a seek mode. The driver includes a current sense amplifier to detect a coil current within the voice coil motor. The coil current is supplied by a center tap coupled to the driver and the voice coil motor. The driver also includes a current command to specify a command current having a waveform. The driver also includes a comparator coupled to the current sense amplifier to receive the current command and shape the command current waveform according to a waveform of the coil current. The driver also includes a bipolar switch coupled to the comparator to turn on and off a set of transistors to supply the command current to the center tap~~the first transistor sends the coil current through the center tap in a first direction, sends a first portion of the coil current through the first coil and sends a second portion of the coil current through the second coil, and the first and second amplifiers and the second transistor are turned off in response to a first seek operation that moves the head across the disk in a first radial direction, and the second transistor sends the coil current through the center tap in a second direction opposite the first direction, sends a first portion of the coil current through the first coil and sends a second portion of the coil current through the second coil, and the first and second amplifiers and the first transistor are turned off in response to a second seek operation that moves the head across the disk in a second radial direction opposite the first radial direction.

~~According to another embodiment of the present invention, a driver for controlling a voice coil motor during a retract mode is disclosed. The voice coil motor has a first coil motor and a second coil motor. The driver includes a sensor to sense a velocity voltage across the second coil motor. The driver also includes an error amplifier to calculate a differential between~~

~~the velocity voltage and a command voltage. The driver also includes a retract amplifier to compensate the command voltage with the differential.~~

~~According to another embodiment of the present invention, a method for controlling a voice coil motor having a first coil motor and a second coil motor with a driver during a retract mode is disclosed. The method includes detecting a velocity voltage with the second coil motor. The method also includes determining a differential voltage between the velocity voltage and a command voltage. The method also includes compensating the command voltage with the differential voltage.~~

It is ~~to be~~ understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

<u>BRIEF DESCRIPTION OF THE DRAWINGS</u>

The accompanying drawings~~, which are included to~~ provide further understanding of the invention ~~and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention~~ and together with the <u>detailed</u> description serve to explain the principles of the invention. ~~In the drawings:~~

FIG. 1 illustrates a disk drive <u>that includes</u> ~~with~~ a <u>driver and a</u> voice coil motor ~~in accordance with an embodiment of the present invention~~;

FIG. 2 illustrates <u>the driver and the</u> ~~a pure torque~~ voice coil motor driver <u>during</u> ~~configured~~ <u>a</u> ~~to a~~ track-following <u>operation</u> ~~mode~~ in accordance with an embodiment of the present invention;

FIG. 3 illustrates <u>the driver and the</u> ~~a pure torque~~ voice coil motor driver <u>during a</u> ~~configured to a~~ seek <u>operation</u> ~~mode~~ in accordance with an embodiment of the present invention; and

FIG. 4 illustrates <u>the driver and the</u> ~~a pure torque~~ voice coil motor <u>during a retract operation</u> ~~configured to a ramp load mode~~ in accordance with an embodiment of the present invention.

<u>DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS</u>

Reference will now be made ~~in detail~~ to the preferred embodiments of the present invention, examples of which are illustrated in detail with the accompanying drawings.

~~A motor driver and ramp loading circuit is disclosed for a VCM. The VCM has two coils, or coil motors, that allow dual modes of operation. During access, the two coil motors are driven with the same polarity to generate the access torque. During tracking, the two coil motors are driven with opposite polarity forming a force couple. The force couple produces the desired amount of torque needed to follow a track while eliminating the reaction forces on the motor bearing. By eliminating the reaction forces on the bearing, a reduction in both bearing wear and run-out is achieved. The improved tracking due to bearing run out reduction would lead to an increase in the disk file storage capacity.~~

~~Embodiments of the present invention include a motor driver having three modes of operation. First is a switch mode peak current controller for access operations. Second is a linear mode class AB amplifier current controller for track following. Third is a linear mode velocity controller for ramp load.~~

~~During access, the switch mode controller allows shaping of the motor current waveform without an increase in the power consumption. A reduction in the seek acoustic may be achieved by shaping the access current waveform. During ramp load the motor driver may utilize one of the VCM coils as a velocity transducer while using the other coil to provide the needed torque to regulate the VCM velocity in a continuous manner.~~

~~Fig. 1 depicts a disk drive 10 with a voice coil motor in accordance with an embodiment of the present invention. Disk drive 10 may be a magnetic hard disk drive. Disk drive 10 reads and writes data to the storage media 28. Storage media 28 may be magnetic storage media that is mounted on spindle 29 and rotated by spindle motor 27. Actuator 18 moves read/write heads 30 across storage media 28 in response to commands from a host. VCM 20 comprises voice coils 26 and provides the force necessary to move actuator 18. VCM 20 employs voice coils 26 that varies a magnetic field in the proximity of a permanent magnet 32. The magnetic field varies by changing the current within VCM coils 26~~

~~Microprocessor 12 implements a servo controller program by executing an estimator 38 control loop program. This action controls the current to VCM 20 through digital-to-analog converter 22 and current driver 36. Current driver 36 provides current to VCM 20 through line~~

~~35. Microprocessor 12 receives servo position information read by head 30 from media 28. The position information is amplified by pre-amplifier 31 and demodulated by servo channel 25.~~

~~VCM 20 may be a pure torque voice coil motor. Torque is created due to motion of the arm and due to mechanical disturbances. A way to reduce torque is to implement a pure torque motor around the center of gravity of the moving mass. The disturbance forces are balanced. The principle behind the pure torque VCM is not to waste any moment, and try to utilize all the torque. All electrical energy put into the coil winding to move the motor is going to change into torque for the desired motion.~~

~~In a preferred embodiment, a stacked coil, pure torque motor is implemented. The stacked coil embodiment uses an additional coil, or two coils over each other. When the current is driven in the coil in the same direction, an axis torque is generated. When the current is driven in the opposite direction, a force couple is generated that is balanced around the bearing of the assembly mass.~~

~~Another approach may be shaving the magnetic circuit and using a permanent magnetic/stationary part of the motor as the coil is moving. An additional coil, however, should be less costly than an additional magnet.~~

Fig. 2 shows driver 26 and VCM 30 during ~~depicts a pure torque voice coil motor driver configured to~~ a track following operation ~~mode~~ in accordance with an embodiment of the present invention.

~~Track following mode indicates that the mechanical assembly is moving the head to follow a track. A force couple should be created, as disclosed above. Actuator assembly 200 includes VCM 204. Driver 202 provides current and control for VCM 204. Driver 202 may receive commands from a microprocessor and current commands from a DAC to place VCM 204 into different modes or to perform various operations.~~ Driver 26 includes ~~202 may be integrated in the~~ power ~~integrated~~ chip 40, sense resistors 42 and 44, capacitor 46 and phase resistor 48. Power chip 40 is an integrated circuit (IC) ~~("IC") that is~~ located on a printed circuit board (not shown) in disk drive 10, and resistors 42, 44 and 48 and capacitor 46 are discreet components external to power chip 40~~the drive PCB~~.

Driver 26 also includes, within power chip 40, transconductance amplifier 50, comparator 52, error buffer 54, amplifiers 56 and 58, transistors 60 and 62, reference voltage generator 64, voltage shifter 66 and switch 68. Transconductance amplifier 50 is a voltage-to-current converter. Comparator 52 provides an error current based on the difference between the input currents. Error buffer 54 provides a buffer amplifier between capacitor 46 and comparator 52 at the input and amplifiers 56 and 58 at the output. Amplifiers 56 and 58 provide the coil current during selected operations. Transistors 60 and 62 are DMOS transistors that provide the coil current during selected operations. Reference voltage generator 64 generates a reference voltage (Vref) based on a supply voltage (Vcc) from an external power supply. Voltage shifter 66 generates half the supply voltage (Vcc/2) based on the supply voltage. Switch 68 connects driver 26 to the power supply when the supply voltage is present during normal operation of disk drive 10 that includes seek and track following operations and disconnects driver 26 from the power supply when the supply voltage is absent.

VCM 30 includes coil 34 which includes coils 70 and 72 and center tap 74. Coils 70 and 72 are separate stacked coil windings that provide separate motors and generate separate magnetic fields in response to the coil current to create separate rotational forces within VCM 30. Coils 70 and 72 are coupled at center tap 74.

Interface 76 is located between driver 26 and VCM 30 and consists of terminals 80, 82 and 84. Amplifier 56 is coupled to terminal 80 by sense resistor 42, amplifier 58 is coupled to terminal 82 by sense resistor 44, and transistors 60 and 62 are directly connected to terminal 84. Likewise, amplifier 56 is coupled to coil 70 by terminal 80, amplifier 58 is coupled to coil 72 by terminal 82, and transistors 60 and 62 are coupled to center tap 74 by terminal 84. Furthermore, amplifier 56 is coupled to coil 72 and center tap 74 by coil 70, amplifier 58 is coupled to coil 70 and center tap 74 by coil 72, and transistors 60 and 62 are coupled to coils 70 and 72 by center tap 74. Advantageously, interface 80 is a three-terminal interface rather than a four-terminal interface, as is conventional for VCMs with dual coils.

~~VCM 204 may comprise two separate motors, coil motor 206 and coil motor 210. Coil motors 206 and 210 also may be known as coils. Coil motors 206 and 210 comprise coil windings that receive a current to create a magnetic field. Coil motors 206 and 210 are connected to a center tap 208. Thus, instead of four terminals from VCM 204 for two different~~

~~coil motors, three terminals are used to create the force couple according to the present invention. By connecting the coils of coil motors 206 and 210 in this manner, each coil will induce a magnetic field in the opposite direction of the other coil.~~

Amplifiers 56 and 58 provide the coil current through coils 70 and 72 during the track following operation. In particular, amplifiers 56 and 58 operate as a class AB amplifier, transistors 60 and 62 are turned off (the gates are coupled to ground), the coil current flows through coils 70 and 72 in series and center tap 74 floats. Driver 26 provides the coil current through coil 34 as though it is a single coil without a center tap, coils 70 and 72 provide opposing rotational forces in opposite rotational directions and head 12 is maintained over the selected track on disk 14.

Driver 26 provides the coil current as an approximation of the command current received from microprocessor 22 via DAC 24 during the track following operation. The coil current flows through sense resistors 42 and 44, coils 70 and 72 and terminals 82 and 82 in series. Sense resistors 42 and 44 have low resistance and therefore little affect on the coil current. Sense resistor 42 provides a sense voltage that corresponds to the coil current, and transconductance amplifier 50 converts the sense voltage into a sense current which corresponds to the coil current. Comparator 52 provides an error current as the difference between the command current and the sense current. Capacitor 46 integrates the error current to provide an integrated error current. Phase resistor 48 provides phase lead in the integrated error current. Error buffer 54 provides the integrated error current to amplifiers 56 and 58, and amplifiers 56 and 58 amplify the integrated error current to provide the coil current to VCM 30.

Driver 26 implements a current feedback loop that adjusts the coil current in response to the difference (error) between the coil current and the command current so that the coil current is about equal to the command current. Advantageously, integrating the error current increases gain in the current feedback loop and reduces steady state error in the current feedback loop. Moreover, introducing phase shift in the integrated error current offsets or cancels phase shift due to a motor electrical time constant of VCM 30. In this manner, capacitor 46 and phase resistor 48 provide a dynamic compensator in which capacitor 46 functions as an integrator and resistor 48 functions as a phase corrector. The dynamic compensator provides the current feedback loop with ~~If two coils are connected in series, and not with the center tap, and current is~~

~~driven from one terminal to the other terminal, then a force couple may be created. For example, if current is driven from the terminal for coil motor 206 to the terminal for coil motor 210, then VCM 204 may create a force couple. The force couple may be a certain percentage of the available torque, but would eliminate the reaction forces on the mechanical assembly of VCM 204. Therefore, in track following mode, driver 202 may see only one coil with center tap 208 disconnected.~~

~~Center tap 208 may be driven by two DMOS transistors 220 and 222. With center tap 208 disconnected, the gates of transistors 220 and 222 are connected to ground. Transistors 220 and 222 are turned off, or "floating."~~

~~Driver 202 includes amplifiers 216 and 218 in a known AB amplifier configuration. Amplifiers 216 and 218 may deliver the current to drive VCM 204. Amplifiers 216 and 218 receive current from error buffer amplifier 233. The amount of current may be determined by a VCM current command 230. Current command 230 may be generated by a microcontroller coupled to driver 202. Current command 230 is received at error buffer amplifier 233, which then indicates to amplifiers 216 and 218 the amount of current to drive VCM 204.~~

~~Driver 202 may desire to know whether the current through VCM 204 is at or about the current specified by current command 230 from the DAC programming. The claimed embodiments of the present invention detect the current within VCM 204 and controls the current from amplifiers 216 and 218 to approximate the current defined by current command 230. Transconductance amplifier 226 and integrator/compensator 224 detect an error current within VCM 204 and integrate the error current into the command current.~~

~~Referring back to VCM 204, a coil current may be sensed through the coil windings by sensor 212. Preferably, sensor 212 is a resistor. More preferably, sensor 212 is a resistor having low resistance. Sensor 212 may be external to driver 202. The current across sensor 212 creates a sense voltage between VCMA and SENAL in Fig. 2. Current sense amplifier 232 detects the sense voltage. Accordingly, VCMA may be sense amplifier HI and SENAL may be sense amplifier LO.~~

~~Current sense amplifier 232 amplifies the sense voltage to be fed into transconductance amplifier 226. Transconductance amplifier 226 amplifies and converts from voltage to current the difference between the VCM current command 230 voltage and the amplified current sense~~

~~voltage. The error current from tranconductance amplifier is fed into a dynamic compensator network 224. Compensator 224 includes a capacitor and a resistor. The capacitor serves as an integrator for the error current. By adding integration, the current control loop gain is increased and the loop steady state error may be eliminated. A phase lead term may be produced by adding a resistor in series to the capacitor. The phase lead term is designed to cancel the phase lag introduced by a motor electrical time constant. The current control loop bandwidth may be increased by compensating for the phase lag introduced by the motor electrical time constant. Thus, an improved loop transient response~~ increased bandwidth to improve~~may result and better tracking in~~ track following~~mode may be enabled by the increased loop bandwidth~~.

~~The control of the current is driven by the sensed current through sensor 212. Sensor 214 also may be included in the sensing circuit. Preferably, the current in the windings of VCM 204 should be about equal with the current specified by command 230. The current control loop bandwidth should be high enough to meet the transient response of the driver system.~~ For example, the current feedback loop has a bandwidth ~~should be anywhere~~ from about 20 kHz to 30 kHz to provide the necessary transient response~~of bandwidth~~.

~~By adding the integrator/compensator 224 after the error current is determined, the potential for DC error is reduced. Integrator/compensator 224 includes a resistor in series with the capacitor. A time constant may be built with integrator/compensator 224, causing a time phase lag.~~

~~Thus, embodiments of the claimed invention disclose building a transconductance current control for VCM 204. The error current is determined and integrated into the command current. The integrated current drives amplifiers 216 and 218 to deliver the winding current.~~

~~The overall current control loop may be referenced to an internally generated reference voltage. Current sense amplifier 232, transconductance error amplifier 226 and error buffer amplifier 233 operate in a bipolar fashion around the internally generated reference voltage. Amplifier 234 is used to generate the driver voltage reference. In order to drive the VCM winding differentially in a symmetrical fashion, the output voltage drive has to be level shifted to half of the supply voltage VISOV/2. The amplifier 236 is used to generate VISOV/2 for the output amplifier. Symmetrical drive around VISOV/2 may be important during the access mode where the HDD seek performance is insensitive to the seek direction.~~

~~Class AB output amplifiers 216 and 218 are biased by the VISOV voltage. The VISOV voltage is connected to the spindle motor driver bridge. During normal operation, the VISOV voltage is connected to the disk drive power supply VCC via switch 238. When power is absent, switch 238 is opened and VCM driver 202 uses the voltage generated by the spindle rectified BEMF as its power supply to perform retract and ramp load.~~

Fig. 3 shows ~~depicts a pure torque voice coil motor~~ driver 26 and VCM 30 during ~~configured to~~ a seek operation~~mode~~ in accordance with an embodiment of the present invention.

Driver 26 also includes, within power chip 40, programmable comparator 86, polarity comparator 88, predriver logic circuits 90 and 92 and transistors 94, 96, 98 and 100. Programmable comparator 86 provides control signals based on a comparison between the command current and the sense current as well as time off (Toff) programming. Polarity comparator 88 provides control signals based on the polarity of the command current. Predriver logic circuit 90 enables and disables (turns on and off) transistors 60, 94 and 96 based on the control signals from comparators 86 and 88, and predriver logic circuit 92 enables and disables (turns on and off) transistors 62, 98 and 100 based on the control signals from comparators 86 and 88.

Transistors 94 and 96 are coupled to terminal 80 by sense resistor 42, and transistors 98 and 100 are coupled to terminal 82 by sense resistor 44. Likewise, transistors 94 and 96 are coupled to coil 70 by terminal 80, and transistors 98 and 100 are coupled to coil 72 by terminal 82. Furthermore, transistors 94 and 96 are coupled to coil 72 and center tap 74 by coil 70, and transistors 98 and 100 are coupled to coil 70 and center tap 74 by coil 72.

Transistors 60, 62, 94, 96, 98 and 100 provide the coil current through coils 70 and 72 during seek operations. In particular, transistors 60, 96 and 100 are turned on, amplifiers 56 and 58 and transistors 62, 94 and 98 are turned off and the coil current flows through center tap 74 and flows in parallel through and is divided approximately equally between coils 70 and 72 during a seek operation in which head 12 moves across disk 14 in a first radial direction. Likewise, transistors 62, 94 and 98 are turned on, amplifiers 56 and 58 and transistors 60, 96 and 100 are turned off and the coil current flows through center tap 74 and flows in parallel through and is divided approximately equally between coils 70 and 72 during a seek operation in which head 12 moves across disk 14 in a second radial direction. Driver 26 provides the coil current

through coil 34 and center tap 74, about one-half the coil current through coil 70 and about one-half the coil current through coil 72, coils 70 and 72 provide additive rotational forces in the same rotational direction and head 12 moves across disk 14 to the selected track during seek operations in both radial directions.

Driver 26 provides the coil current based on the command current received from microprocessor 22 via DAC 24 during the seek operation. The coil current flows through center tap 74 and terminal 84, at which point it is divided into a first portion (about one-half the coil current) that flows through sense resistor 42, coil 70 and terminal 80 in series and a second portion (about one-half the coil current) that flows through sense resistor 44, coil 72 and terminal 82 in series. Sense resistors 42 and 44 provide a sense voltage that corresponds to the coil current, and transconductance amplifier 50 converts the sense voltage into a sense current which corresponds to the coil current.

Programmable comparator 86 provides high (asserted or logical "one") control signals to predriver logic circuits 90 and 92 until the sense current reaches the command current, and then programmable comparator 86 provides low (deasserted or logical "zero") control signals and activates the Toff counters set by the Toff programming so that the control signals remain low until the Toff period expires. Thereafter, the cycle repeats itself. Thus, programmable comparator 86 drives transistors 60 and 62 into saturation with pulse width modulation (PWM) independently of the integrated error current, and the PWM has a duty cycle that is active based on the magnitude of the coil current relative to the command current and is inactive based on the predetermined Toff period.

Polarity comparator 88 compares the command current with the reference voltage to determine the polarity of the command current, which indicates the radial direction of the seek operation, and provides control signals to predriver logic circuits 90 and 92 based on the polarity of the command current. Polarity comparator 88 provides a high control signal that turns on transistors 60, 96 and 100 and a low control signal that turns off transistors 62, 94 and 98 if the command current is less than the reference voltage and therefore indicates that the seek operation occurs in the first radial direction, and polarity comparator 88 provides a low control signal that turns off transistors 60, 96 and 100 and a high control signal that turns on transistors 62, 94 and 98 if the command current is greater than the reference voltage and therefore indicates that the

seek operation occurs in the second radial direction. ~~Seek mode indicates that the mechanical assembly is moving the head to find, or seek, a track. The two coils of VCM 204 are driven in parallel. Actuator assembly 200 includes driver 202 and VCM 204. Driver 202 provides current and control for VCM 204. Driver 202 may receive commands from a DAC to place VCM 204 into different modes or to perform various operations.~~

~~In linear motor driver technology, the temperature rise in the motor driver integrated chip may be due to increased power dissipation. This dissipation, in turn, prohibits the shaping of the motor current waveform that flows through the coils. Operations to shape the motor current waveform eliminates the acoustic noise produced by the disk drive while in seek mode. In modern disk drive applications, an increasing need for reducing the amount of acoustic noise is desired during seek operations. Embodiments of the present invention may allow shaping of the motor current without an increase in the power dissipation in the motor driver integrated chip.~~

~~In seek mode, the AB amplifiers 216 and 218 of Fig. 1 are disabled. The gates of DMOS transistors 220 and 222 are controlled by logic elements of driver 202 to provide current to VCM 204. Transistors 220 and 222 may be known as "bore" transistors. Driver 202 delivers the current to center tap 208. By receiving the current from center tap 208, coil motors 206 and 210 are driven in parallel.~~

~~For switching operations, driver 202 is turned on for a certain duty cycle with driver 202 controlling the actuator in one direction to achieve the current received by the DAC programming, or the command current 230. Once achieved, the driver is switched to off. Under this operation, driver 202 may be known as a peak current, switch driver. Current in the coils would equal the command current at their peaks.~~

~~According to embodiments of the present invention, driver 202 may be turned on for a saturation period depending on the current valve from DAC 230, and then turned off for a constant period of time. Driver 202 turns on the appropriate transistors depending on the polarity of the commanded current from DAC 230. The output voltage of motor current sense amplifier 232 is about equal to the sum of current in both coil motors 206 and 210. When comparator device 302 detects that the motor winding current sum has reached the commanded current, driver 202 is switched off. The current in each winding rises to about half of the command current. The "off" period may be programmable by a microprocessor and may determine the~~

~~switch mode operation duty cycle. Thus, driver 202 in seek mode may be known as a constant off time peak current controller.~~

Predriver logic circuit 90 includes an AND gate that turns on transistor 60 if the control signals from comparators 86 and 88 are high, and predriver logic circuit 92 includes an AND gate that turns on transistor 62 if the control signals from comparators 86 and 88 are high.

During a seek operation in the first radial direction, comparators 86 and 88 send control signals that command predriver logic circuit 90 to turn on transistors 60 and 96 and turn off transistor 94, and command predriver logic circuit 92 to turn off transistors 62 and 98 and turn on transistor 100. As a result, transistor 60 sources the coil current from the power supply through center tap 74, the first portion of the coil current flows in series through coil 70, sense resistor 42 and transistor 96 to ground, and the second portion of the coil current flows in series through coil 72, sense resistor 44 and transistor 100 to ground.

During a seek operation in the second radial direction, comparators 86 and 88 send control signals that command predriver logic circuit 90 to turn off transistors 60 and 96 and turn on transistor 94, and command predriver logic circuit 92 to turn on transistors 62 and 98 and turn off transistor 100. As a result, transistor 94 sources the first portion of the coil current from the power supply through sense resistor 42 and coil 70 to center tap 74, transistor 98 sources the second portion of the coil current from the power supply through sense resistor 44 and coil 72 to center tap 74, and the coil current flows in series through center tap 74 and transistor 62 to ground.

~~For example, DMOS transistor 220 is saturated to control VCM 204 into a certain direction. The driver current flows from driver 202 to center tap 208. When the driver current reaches about one half the amount specified by current command 230, then transistor 220 switches off. Driver 202 keeps transistors 220 and 222 off for a certain period of time. When the period is finished, transistor 220 is saturated again to get the driver current flowing back through center tap 208.~~

Driver 26 functions as a bipolar peak current switch driver with constant off-time during seek operations. Driver 26 reduces power consumption in power chip 40 by operating transistors 60 and 62 as saturated bore transistors, thereby reducing temperature rise in power chip 40~~Full saturation in turning on and off the transistors may improve the efficiency of driver 202. Further,~~

~~the power consumption in driver 202 may be reduced. The power transistor saturates during the "on" phase, thereby reducing the power dissipated in the power IC to drive the motor windings.~~ This permits microprocessor 22 to waveform shape the command current to eliminate acoustic noise during seek operations even though the waveform shaping increases power consumption and temperature rise in power chip 40.~~Thus, efficiency may be improved and power consumption reduced. Using this technique during seek mode may allow driver 202 to use any waveform shape of current to drive VCM 204. During seek mode, if a linear current drive is used, the shaping of the commanded current may increase the power dissipated in the power IC. A temperature rise of the power IC package due to the increase in the power dissipation may prohibit current waveform shaping. Thus, switch mode control for driver 202 may be desired.~~

~~According to embodiments of the present invention, current sense amplifier 232 may provide a sum of the two currents flowing in coil motors 206 and 210. The sum may be about equal to the drive current flowing through center tap 208. Using current sense amplifier 232, driver 202 may avoid using independent current switch power control loops. The sum of the motor currents may give the torque created by VCM 204 because coil motor 206 and coil motor 210 are being driven in the same direction. Driver 202 should be an accurate torque driver for the two coil motors 206 and 210. Thus, driver 202 may avoid running the coil motors 206 and 210 on two different loads. Preferably, driver 202 is configured to be a bipolar peak current driver, or control, for a switch mode.~~

~~Referring to Fig. 3, current sense amplifier 232 detects the coil current flowing through coil motors 206 and 210. The coil current may be the same as the driver current flowing through center tap 208. Current sense amplifier 232 may amplify the coil current. Comparator device 302 receives the output from current sense amplifier 232 and a command current specified by current command 230. Comparator device 302 detects when the output voltage of current sense amplifier 232 reaches the VCM current command of DAC 230 and then turns off driver 202. Driver 202 stays off for the period specified by Toff programming, and then turned back on. The process may repeat itself.~~

~~Comparator 304 determines the polarity of the commanded current and programs predriver logic 310 and 312 to turn on the appropriate transistors. If the commanded current is greater than VREF, then both of the high side transistors 306 and 308 are turned on. The low~~

~~side center tap driver transistor 222 may be controlled by the constant Toff chapper while the high side center tap driver transistor 220 is off. During the driver cycle, the winding A current comes from the power supply via high side transistor 306, passes through winding A, then passes through transistor 222 to ground while the winding B current comes from the power supply via high side transistor 308, passes through winding B, then passes through transistor 222 ground.~~

~~Thus, any shape for the waveform of the command current may be used to drive VCM 204 without increasing power consumption within driver 202. Further, reduction in acoustic forces within the disk drive may be achieved by shaping the command current waveform.~~

Fig. 4 <u>shows driver 26 and</u> ~~depicts a pure torque~~ voice coil motor <u>30 during a</u> ~~driver configured to a ramp load, or~~ retract <u>operation</u>~~, mode~~ in accordance with an embodiment of the present invention.

~~Storage media heads may use ramp loading technology to achieve the forecasted capacity growth of the disk drive. Known ramp loading schemes suffer from the absence of an accurate velocity transducer to control the ramp load and unload velocity. The velocity tolerance of the ramp loading may effect the reliability of the disk drive. Schemes may use continuous feedback of the velocity by sampling the back electro-magnetic force to provide an acceptable tolerance, but require a complex switch mode operation of the ramp load controller, or driver. Switch mode operation, however, may create undesirable acoustic noise during ramp load.~~

<u>Disk drive 10 retracts head 12 from disk 14 and loads head 12 on a ramp (not shown) during the retract operation. Disk drive 10 performs the retract operation as it powers down so that head 12 remains parked on the ramp until power is restored. Furthermore, since the supply voltage is absent, switch 68 disconnects driver 26 from the power supply, and driver 26 uses rectified back electromagnetic force (BEMF) voltage from spindle motor 16 to perform the retract operation.</u>

<u>Driver 26 also includes, within power chip 40, retract sequencer 102, reference retract velocity generator 104, amplifier 106 and predriver logic circuit 108. Retract sequencer 102 provides control signals that retract head 12, brake spindle motor 16 and brake VCM 30 in response to detecting the supply voltage is absent. Reference retract velocity generator 104 provides a reference retract velocity for moving head 12 from disk 14 to the ramp during the retract operation based on retract velocity programming. Amplifier 106 operates transistors 60</u>

and 62 to control the coil current in order to increase the retract velocity, decrease the retract velocity or set the retract velocity to the reference retract velocity based on the retract head control signal, the brake VCM control signal and the integrated error current. Predriver logic circuit 108 controls transistors 94 and 96 in response to the brake VCM control signal, and transistors 98 and 100 have their gates coupled to ground.

Driver 26 operates during the retract operation in several respects like the track following operation. The coil current flows through coil 34 and sense resistors 42 and 44, sense resistors 42 and 44 provide a sense voltage that corresponds to the coil current, transconductance amplifier 50 converts the sense voltage into a sense current, comparator 52 provides an error current as the difference between the command current and the sense current, capacitor 46 integrates the error current to provide an integrated error current, phase resistor 48 phase shifts the integrated error current and the coil current is adjusted based on the integrated error current using a current feedback loop. However, during the retract operation, the command current specifies the retract velocity, and driver 26 provides the coil current as an approximation of the command current to achieve the retract velocity.

Driver 26 operates during the retract operation in other respects like the seek operation. Retract sequencer 102 sends control signals to amplifier 106 and predriver logic circuit 108 that cause transistors 60, 62, 94 and 96 to provide the coil current necessary to make coil 34 move head 12 from disk 14 to the ramp at the desired retract velocity. Furthermore, d~~Embodiments of the present invention may use the second coil motor as a velocity transducer to provide a continuous velocity feedback to driver 202. The motor driver ramp loading circuit is a closed loop linear velocity regulator.~~river 26 uses coil 70 to control the motion of head 12 and coil 72 as a velocity transducer to provide continuous velocity feedback. In this manner, ~~The regulator uses a first coil motor to control the motion while the second coil motor is used to sense the velocity.~~driver 26 functions as a closed loop linear velocity regulator. Advantageously, driver 26 provides accurate retract velocity control that reduces mechanical wear on the ramp, thereby increasing~~Embodiments of the present invention should provide the needed precision of the ramp load and unload velocity.~~

~~Ramp load schemes attempt to park the head when the disk is not rotating. The head may be lifted and parked. Power may be detected as decreasing, and the actuator is moved with the~~

~~head to unload the head from the disk. When the disk is rotating again, driver 202 may load the head back onto the disk. In performing ramp load operations, disk drives should be careful not to hit the ramp too fast. Wear and tear on mechanical components may occur, and reduce~~ the lifetime of ~~the~~ disk drive <u>10</u>.

~~Referring to Fig. 4, the coil within second coil motor 210 may be used as a velocity transducer along with a sensor 420 to sense the velocity of VCM 204. Once in track mode, VCM 204 may be tri-stated. Thus, coil motor 206 may be used to control the motion of the head, while coil motor 210 may be used to sense the velocity.~~

~~Coil motor 210 produces a voltage across VSENBL and VCMCT. Sensor 420 may be a resistor that senses the voltage across the terminals. Differential amplifier 232 detects the voltage and produces an output to error amplifier 226. Differential amplifier 232 may be the same logic element as current sense amplifier 232, but is referred to differently because of the difference in functionality with regard to the ramp load mode. Error amplifier 226 may be the same logic element as transconductance amplifier 226, but is referred to differently because of the difference in functionality with regard to the ramp load mode. The output of differential amplifier 232 may be proportional to the velocity of VCM 204, as sensed by coil motor 210 and sensor 420.~~

~~Error amplifier 226 calculates the error, or the difference, between the measured velocity and a command velocity 402 from the DAC programming. Error buffer amplifier 233 amplifies the error and provides the error to retract amplifier 406. The retract linear velocity control loop may be compensated dynamically with the resistor and capacitor compensation network 224. Compensation network 224 may include the same elements as the track following transconductance loop compensation network of Fig. 2. Retract amplifier 406 drives coil motor 204 to increase or reduce velocity, and to set motor velocity to the programmed velocity specified in velocity command 402. Transistors 220 and 222 may deliver the current to drive coil 206, as disclosed above. Therefore, driver 202 may configure itself to be a retract velocity regulator control loop when in ramp load, or retract, mode.~~

~~Embodiments of the present invention may provide a continuous analog loop to perform constant velocity retract, or to control velocity ramp load or retract. With a continuous analog loop, embodiments may design the loop with a much wider bandwidth without perceivable~~

~~steady-state error. Switch mode techniques no longer may be needed. Noise and complicated circuitry to implement the switch mode may be reduced, which, in turn, reduces costs to driver 202. Thus, a more precise controller with increased bandwidth may be used to perform ramp load.~~

~~During power on, ramp load and unload operations, the VCM current command of DAC 230 may be used as the VCM velocity command of DAC 402. During power off, a retract velocity reference 404 is used to set the desired velocity for unloading the heads. If power is lost during a VCM seek towards the ramp, a power down retract sequencer logic 412 may be used to brake the VCM 204 using both motor coils before engaging the linear velocity controller.~~

Disk drive 10 can include the single actuator arm 30 described above, or alternatively, multiple actuator arms 30 arranged in a comb-like fashion extending from the pivot point, with each actuator arm 30 supporting a separate head 12 that reads data from and writes data to a separate disk surface of disk or disks 14.

VCM 30 can include coils 70 and 72, or alternatively, the magnetic circuit can be shaved and a permanent magnetic/stationary part of VCM 30 can be used although an additional coil should be less costly than an additional magnet.

It will be apparent to those skilled in the art that various modifications and variations can be made in ~~a probe head of~~ the driver ~~present invention~~ without departing from the spirit or scope of the invention. Thus, it is intended that the present invention covers the modifications and variations of this invention provided that they come within the scope of the~~any~~ claims~~ and their equivalents~~.

ABSTRACT~~ OF THE INVENTION~~

A driver ~~device and method~~ for a~~pure torque~~ voice coil motor in a disk drive ~~is disclosed. The driver includes a current control device for the voice coil motor. The driver also~~ includes a sensor that provides a sense current by ~~to~~ sensing~~e~~ a coil current in~~to~~ the voice coil motor, a comparator that provides an error current by determining a difference between a command current and the sense current, an integrator that provides an integrated error current by integrating the error current, and an amplifier that provides the coil current by amplifying the integrated error current.~~ The driver also includes a transconductance amplifier to detect an error current from the coil current and a command current. The driver also includes an integrator/compensator to integrate the error current into the coil current. In another configuration, the driver is a driver having a current controller for the voice coil motor in a seek mode. The driver includes a set of transistors coupled to the voice coil motor by a center tap. The set of transistors supply a coil current having a waveform to the center tap. The driver also includes a current sense amplifier to detect the coil current. The driver also includes a comparator to shape a command current waveform to the coil current waveform. The driver also includes a bipolar switch control to receive the command current waveform and to saturate the set of transistors. In another configuration, the driver is a driver for controlling the voice coil motor during retract mode. The voice coil motor has a first coil motor and a second coil motor. The driver includes a sensor to sense a velocity voltage across the second coil motor. The driver also includes an error amplifier to calculate a differential between the velocity voltage and a command voltage. The driver also includes a retract amplifier to compensate the command voltage with the differential.~~